

Wireless Communication Systems Design for Tactical Software-Defined Radios – From Scenario-Based Analysis to Channel and Waveform Parameter

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ABSTRACT

Software defined radios and especially the associated digital waveforms for tactical wireless communication systems feature a high degree of freedom and can be tailored to completely different operational needs. In case of the development of new digital waveforms which can not be adopted from existing ones, methods for technical parameter definition have to be found. In this paper a method based on 'scenario based analysis' is presented which allows a technical parameter definition in dependency on operational needs. Exemplary this method is demonstrated for the definition of channel models and waveform parameters, the physical OSI layer (open systems interconnection reference model) of a communication system. Possible extensions of the method, e.g., for defining parameter of higher OSI layer are indicated. The work for this paper was motivated by current activities in civil and military sector.

1.0 INTRODUCTION

1.1 Motivation

With the ever increasing performance of general purpose processors (GPP), digital signal processors (DSP) and field programmable gate arrays (FPGA) the software defined radios (SDR) became technically feasible [1], [2]. In opposition to old analogue radios, SDR can implement different standards, such as IEEE-802.11(WiFi-Alliance), IEEE-802.15 (Bluetooth), IEEE-802.16 (WiMAX-Worldwide Interoperability for Microwave Access) or DVB-H (Digital Video Broadcast-Handhelds). Moreover, the SDR are eligible to implement more powerful and more complex waveforms with a higher degree of freedom, for example wideband high data rate networking waveforms [3]. These are currently subject of civil and military development projects. In conjunction with the higher degree of freedom and complexity, the design process and definition of an increasing number of design parameters distributed over all OSI layers (open systems interconnection reference model) gets more challenging [2]. In this paper, the design process for the lower OSI layer, i.e. the physical layer and medium access sublayer will be addressed.

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| 14. ABSTRACT Software defined radios and especially the associated digital waveforms for tactical wireless communication systems feature a high degree of freedom and can be tailored to completely different operational needs. In case of the development of new digital waveforms which can not be adopted from existing ones, methods for technical parameter definition have to be found. In this paper a method based on scenario based analysis is presented which allows a technical parameter definition in dependency on operational needs. Exemplary this method is demonstrated for the definition of channel models and waveform parameters, the physical OSI layer (open systems interconnection reference model) of a communication system. Possible extensions of the method, e.g., for defining parameter of higher OSI layer are indicated. The work for this paper was motivated by current activities in civil and military sector. | | | | | |
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1.2 Challenge and Approach

The selection of a new wide band digital waveform, e.g., a wide band network waveform for tactical SDR, depends on a large number of parameters. Reducing the possible degrees of freedom in the best way for achieving the performance requirements demanded by the operator is therefore the key. A waveform can be optimized, e.g., towards long range operation, highly dynamic mobile environment (i.e. high delay and Doppler) or high data rate to work in different environments like urban, rural or hilly terrain [4]. Moreover, operation with various hardware equipment such as different antenna types (e.g. omnidirectional, directive arrays), different transmitter powers and different frequency ranges may be required. All these requirements have to be translated into technical parameters such as modulation, forward error correction coding and MAC (medium access) schemes. The technical parameters can only be optimized on the basis of suitable propagation channel models [5], [6], [7]. A design method is proposed to derive channel models and subsequently the digital waveform parameter from user scenario based process. This approach will allow for reducing the degrees of freedom in the design in an early phase of the design process and at the same time is supposed provide the operator with optimum functionality for the given use case.

2.0 SCENARIO BASED ANALYSIS

The ‘scenario based analysis’ itself is a method for strategic planning [8]. Beside contingency planning or sensitivity analysis, ‘scenario based analysis’ is a planning method for preparing decisions while a complex set of variables and dependencies has to be considered [8].

The following approach presents a framework for the development of the accurate scenarios as a basis for channel model and waveform development. It will help the operator first to ask the right questions and second the waveform developer to get an almost complete and consistent description (e.g. due to physics) of the desired waveform. As mentioned above, only the design process of the lower OSI layer, i.e. the physical layer and medium access sublayer only will be addressed. Nevertheless, the framework can easily be adopted for the development of higher OSI layer as well.

2.1 Design Flow in Principle

The principle of the design flow is shown in Figure 1 on next page. It comprises two iterative processes:

The first process (depicted in Figure 1 on top, labelled “1”) develops a common view from a mission or user’s point of view and from a communication system’s point of view. This is the first step of the approach and allows a structured way of defining requirements involving both interest groups, the operators and communication systems engineers. The direct links (labelled in Figure 1: “2a”, “2b”) and the second iterative process (indicated in Figure 1 on the bottom: labelled “3”) are the second step of the approach and provide an estimation of the degrees of freedom for the required parameter. An optimum set of key performance parameter for the development of an OSI physical layer, including channel models and digital waveforms, can be found in fulfilment to requirements given by an operator.

The second step of the approach with the direct links and the second iterative process (labelled in Figure 1: “2a”, “2b”, “3”) is the specific of the design flow for the development of the lower OSI layer. It can be replaced or added by different models for other OSI-Layer. The direct link back (labelled in Figure 1: “4”) provide a feedback that necessarily impacts the definition of requirements within the first iterative process.

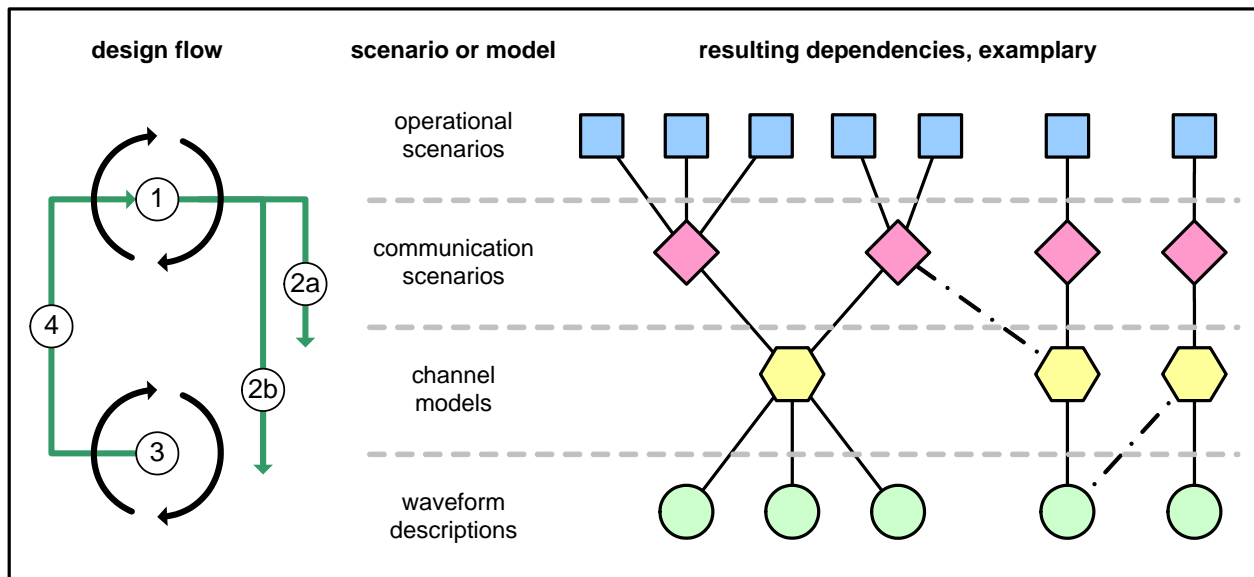


Figure 1: Design Flow and General Dependencies as an Exemplary Result of Scenario Based Analysis.

2.2 First Iterative Process for Operational and Communication Scenarios

First step in design process (labelled “1” in Figure 1) is the definition of operational scenarios AND communication scenarios according to two different sets of requirements. Usually one set of requirements for one set of scenarios is developed without a separation in two kinds of scenarios [8].

The separation, as a part of the approach, seems necessary in this special case of channel model and waveform development for tactical software defined radio. The degrees of freedom and dependencies on the communication site are much higher compared to legacy communication devices and therefore in general can not be overseen by the operator site.

The challenge for this separation is first a clear definition of two sets of requirements which allows two assessments of different operational and communication scenarios. Second, dependencies between the sets of requirements have to be determined which help to cluster operational scenarios and allocate communication scenarios to each cluster (compare Figure 1, resulting dependencies). The allocation only becomes possible, when the impact of one requirement set on the other is known.

An optimization criterion at this stage could be to reach a minimum number of necessary communication scenarios. A merge of two communication scenarios into one communication scenario is possible, if the difference in scenarios does NOT lead to a change either in the channel model or in the waveform description. In the general case one communication scenario leads to one channel model. Nevertheless in case of increased complexity it might be possible that two channel models are suitable for one certain communication scenario in dependency of related operational scenario (depicted in Figure 1 with a dashed line). The same increased complexity in optimization might be possible concerning the waveform description and the communication scenario.

In the following the two requirement sets for operational and communication scenarios including the mutual dependencies are presented, while the dependencies are additionally summarized tabulated additionally in a separate subchapter.

2.2.1 Operational Scenario

The operational scenario describes the deployment of personnel and communication devices from the operator's or user's point of view. Different variables which can be seen in Figure 2, have to be considered during the design process:

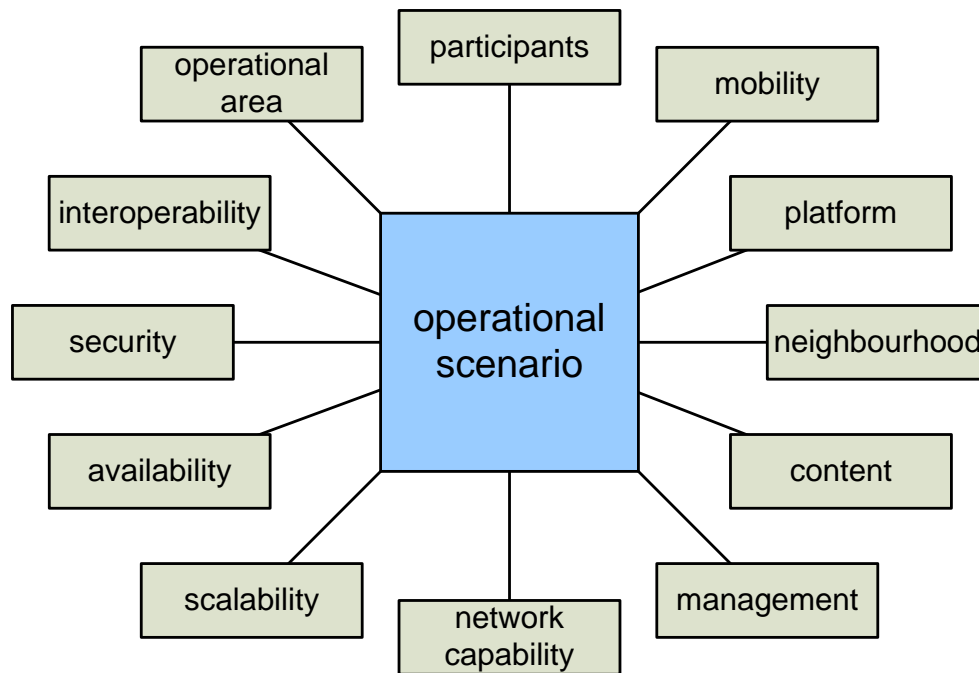


Figure 2: Operational Scenario and Related Variables which Influence Definition from Operator's Point of View.

- *participants:*

The variable 'participants' describes who is taking part in the operational scenario. This includes single persons and certain organized groups as well. They all have in common that they are equipped with communication devices.

- *mobility:*

The variable 'mobility' describes two different dimensions – mobility in space and mobility in time. Mobility in space means the relative velocity between the participants and mobility models in space are addressed. Mobility in time is linked to the total number of participants which at a certain time take or could take part at the communication. Effects on groups described with join, split, merge etc. and their behaviour over time are of interest.

- *platform:*

The variable 'platform' addresses both the different types of communication devices and the carrier platform as well. These might be stationary (e.g. antenna tower) or mobile (e.g. vehicle based, handheld).

- *neighbourhood:*

The variable 'neighbourhood' contains information on external communication groups (e.g. friendly or hostile; types of devices; transmit powers) which are spatially close arranged and are using comparable transmit frequencies.

- *content:*

The variable ‘content’ is focused on communication purpose between different participants in general. Different communication purposes are, e.g., voice, data, video, identification friend or foe (IFF), blue force tracking or fire systems control.

- *management:*

The variable ‘management’ contains different types of prioritisations of the content towards different communication purposes (contents). Also, e.g., hierarchical voice communication structures (one participant dominates) are concerned.

- *network capability:*

The variable ‘network capability’ describes the realizability of two or in general more participants to exchange content. The network capability often is limited by the number of participants or the amount of content which could be exchanged at a certain time.

- *scalability:*

The variable ‘scalability’ is closely connected to the number of participants and the network capability. It addresses the opportunity to increase or decrease the scenario while retaining the main characteristics.

- *availability:*

The variable ‘availability’ is associated with the different content types. There are dimensions of availability can be different, e.g., time, a certain area or a certain group of the participants.

- *security:*

The variable ‘security’ is focused on necessary protection for certain content transmission (e.g. transmission security (TRANSEC) like hopping) or communication security (COMSEC) like encryption).

- *interoperability:*

The variable ‘interoperability’ stands for both exchange of content with friendly neighbourhood and the re-use of one waveform with different hardware communication devices.

- *operational area:*

The variable ‘operation area’ consists of different dimensions. The first dimension is the spatial area for the participants and the maximum distance between. The second dimension is the type of area (e.g. land, sea, air) and locations (e.g. indoor, outdoor) of the participants.

The process of definition of operational scenarios itself is exemplarily documented in [8]. The variables from Figure 2 shall help to ask the right questions and prepare an iterative process for the definition of related communication scenarios.

There are more variables for operational scenario description. The presented variables here are an extract focusing on the exemplary application for development of the channel model and the waveform parameter. Focusing on a different application, e.g., development of the network OSI-layer, appropriate variables may differ or had to be added.

2.2.2 Communication Scenario

The communication scenario describes the deployment of communication devices and communication participants for wireless applications from the system engineer’s point of view.

In contrast to the operational scenarios different variables have to be concerned, as illustrated in Figure 3.

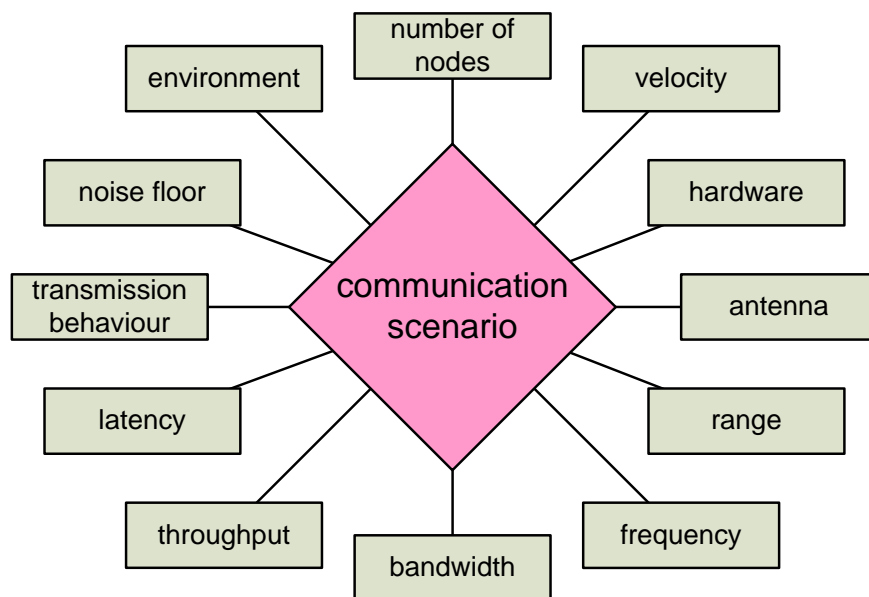


Figure 3: Communication Scenario and Related Variables which Influence Definition from System Engineer's Point of View.

In detail:

- *number of nodes:*

The variable 'number of nodes' represents the number of communication devices which can transmit or receive electromagnetic waves. The number of nodes may differ from the number of participants (e.g. in case of relay stations).

- *velocity:*

The variable 'velocity' describes the maximum relative velocities between the nodes and allows together with the known centre frequency, the calculation of maximum Doppler frequencies.

- *hardware:*

The variable 'hardware' covers the hardware performance parameter of the communication devices focusing on the processing unit and RF (radio frequency) frontend excluding the antenna. These parameter are e.g. transmit power, spurious free dynamic response (SFDR), memory or clock speed.

- *antenna:*

The variable 'antenna' represents the electromagnetic performance parameter of the antenna including different types of antenna (e.g. omni directional, directive arrays) and close surrounding (e.g. car roof).

- *range:*

The variable 'range' describes the reachable spatial distances between the nodes. According to the distance often the desired throughput is added (e.g. short distance ↔ high throughput; long distance ↔ low throughput).

- *frequency:*

The variable ‘frequency’ defines the radio frequency the nodes are using for wireless communication. The frequency is closely related e.g. to the variables range and throughput. Normally the range decreases and the throughput increases with rising frequency in wireless communication because of physical properties.

- *bandwidth:*

The variable ‘bandwidth’ is closely connected to the frequency and defines the reachable spectrum around the frequency for one or more modulation schemes. In general frequency spectrum use is regulated (e.g. centre frequency, bandwidth and signal strength) by government or official agencies.

- *throughput:*

The variable ‘throughput’ is connected to the data rate between the nodes which can differ. The reachable maximum throughput in general increases with rising frequency and rising bandwidth.

- *latency:*

The variable ‘latency’ describes the time for an information packet to get from one certain node to another. The minimum latency may be limited by e.g. the physical channel, signal coding or processing time in hardware.

- *transmission behaviour:*

The variable ‘transmission behaviour’ focuses on the type of RF signal behaviour (e.g. burst signal, continuous signal). Special RF signal behaviour might also be necessary or limited to special waveforms, if capabilities like anti-jam-resistance or low probability of detection are required.

- *noise floor:*

The variable ‘noise floor’ describes undesirable RF-signals in the air which might disturb or interfere the wanted signal. The source of the noise might be natural (e.g. cosmic radiation) or man-made (e.g. unintentional parallel frequency use).

- *environment:*

The variable ‘environment’ covers the different topologies (e.g. rural, hilly, urban) and morphologies (e.g. forest, water, desert) which impacts the electromagnetic wave propagation.

The scenario definition process itself is documented in [8]. The presented variables are also, like the variables for operational scenarios, an extract of all possible variables focused on the channel model and the waveform description. Therefore compare the feedback of the second iterative process on first iterative process in general design flow (Figure 1 on page 3: feedback labelled with “4”). The result of this feedback has a strong impact on the extract of the variables.

2.2.3 Summarized Dependencies of Operational and Communication Scenario

Following,

in

Table 1 the dependencies of the operational scenario and the communication scenario are summarized. In detail, the degree of dependency (strong, weak, none) of the communication scenario variables from the operational scenario variables are presented in the cross matrix.

Table 1: Dependency of Communication Scenario Variables from Operational Scenario Variables.

| | | Operational scenarios | | | | | | | | | | | |
|-------------------------|------------------------|-----------------------|----------|----------|---------------|---------|------------|--------------------|-------------|--------------|----------|------------------|------------------|
| | | participants | mobility | platform | neighbourhood | content | management | network capability | scalability | availability | security | interoperability | operational area |
| Communication scenarios | number of nodes | | | | | | | | | | | | |
| | velocity | | | | | | | | | | | | |
| | hardware | | | | | | | | | | | | |
| | antenna | | | | | | | | | | | | |
| | range | | | | | | | | | | | | |
| | frequency | | | | | | | | | | | | |
| | bandwidth | | | | | | | | | | | | |
| | throughput | | | | | | | | | | | | |
| | latency | | | | | | | | | | | | |
| | transmission behaviour | | | | | | | | | | | | |
| | noise floor | | | | | | | | | | | | |
| | environment | | | | | | | | | | | | |

Legend

strong dependency
 weak dependency
 no dependency

These mutual dependencies help to cluster the operational scenarios and allocate them to a certain communication scenario.

First, if two operational scenarios differ in a variable with no or weak dependency they can be allocated to one communication scenario.

Second, if two operational scenarios differ in a variable with strong dependency, they can be allocated to one communication scenario too, if difference in the variable does NOT change either the channel model or the waveform description. The mutual dependencies from the communication scenario and the channel model/waveform description are presented in detail in next chapter.

2.3 Second Iterative Process for Channel Model and Waveform Description

While the first iterative process of the framework (Figure 1) is suitable for the development of tactical wireless software defined radios in general (e.g. different OSI layer), the following second iterative process is, as already mentioned, tailored to the development of the physical layer.

The physical layer of a software defined radio consists of a waveform description which is in contrast to legacy waveforms partly implemented in software. This allows a higher degree of freedom in implementing and selecting different waveforms while the radio hardware (e.g. RF-frontend) stays the

same. Moreover, compared to legacy waveforms the new digital waveforms offer new features like error correction. This offers the developer the opportunity to tailor the digital waveform to a certain communication and operational scenario.

The challenge in digital waveform development is to set the different parameters (e.g. modulation scheme, coding length) correctly towards the scenario regarding the transmitter/receiver properties and the dependencies on physics (e.g. electromagnetic wave propagation). Therefore the digital waveform development goes along with RF frontend and channel modelling. Without loss of generality for the framework the imperfectness of the radio frontend (e.g. nonlinearities, amplifier noise) will be ignored in the following. It could be added in Figure 1 as a second model with mutual dependencies between the waveform description and the channel model.

Compared to the first iterative process sets of requirements for the channel model and the waveform description has to be set either. The amount of physical properties to be modelled in the channel model depends on the communication scenarios and the desired waveform needs.

In contrast to the first iterative process the channel model fulfils two roles. One the one hand it is the development base and on the other hand the evaluation base for the digital waveform. In the following, the two required sets for channel model and waveform description including the mutual dependencies are presented while the dependencies are additionally summarized at the end of every subchapter.

2.3.1 Channel Model and Mutual Impact on Communication Scenarios

The channel model describes the electromagnetic (EM) wave propagation between two communication devices. Modelling is driven by different influences as presented in the following.

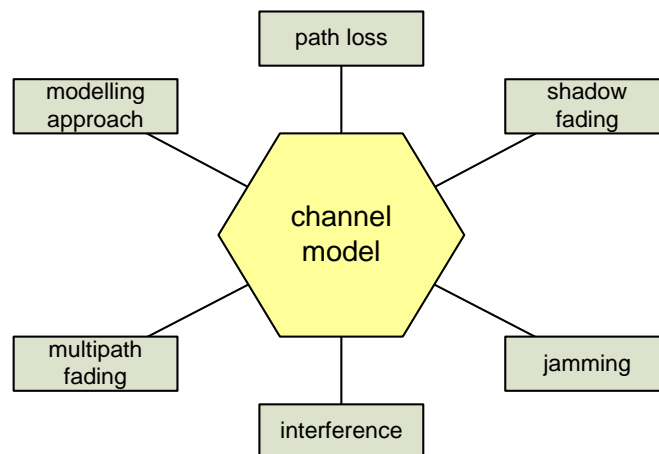


Figure 4: Channel Model and Related Dependencies.

- *modelling approach:*

The wireless channel can be simulated using various approaches like geometry-based or stochastic models, for example the well known Tapped-Delay-Line-Model. Dependent on the communication scenario, especially the environment, different approaches may be more applicable.

- *path loss:*

The decrease in signal strength at the receiver is probably the most obvious phenomenon of a wireless transmission which is to be simulated by the channel model. It not only depends noticeably on the distance between the communicating nodes but also on the type of surrounding environment.

- *shadow fading:*

Shadow fading, sometimes referred to as slow fading, is introduced due to large obstacles like hills or buildings shadowing the signal at the receiver. Commonly modelled by a log-normal distribution, the shadow fading is dependent on the range and environment given in the communication scenario.

- *multipath fading:*

The superposition of signal components arriving at the receiver through different paths by the means of scattering, refraction or reflection causes a variation of the amplitude and phase of the signal. This phenomenon is called multipath fading, sometimes referred to as fast fading. A common way of simulating this kind of fading is by using a Tapped-Delay-Line-Model defined by a power delay profile and Doppler power density spectra. Those depend principally on the environment but also on the frequency and antenna.

- *interference:*

Interference originating from man-made noise may simply be modelled by the AWGN approach. Nevertheless, interference through co-site emissions or signals in adjacent channels should not be neglected and modelled according to the specifications in the scenario.

- *jamming:*

The intended jamming of the signal through a hostile third party also has to be incorporated in the simulation of the wireless channel if the scenario is defined to that effect.

In the following Table 2 on next page the dependencies of channel model influences and communication scenario parameter are summarized again.

Table 2: Dependency of Channel Model Influences from Communication Scenario Variables.

| | | Communication scenario | | | | | | | | | | | |
|---------------|--------------------|------------------------|----------|----------|---------|-------|-----------|-----------|------------|---------|------------------------|-------------|-------------|
| | | number of nodes | velocity | hardware | antenna | range | frequency | bandwidth | throughput | latency | transmission behaviour | noise floor | environment |
| Channel model | modelling approach | | | | | | | | | | | | |
| | path loss | | | | | | | | | | | | |
| | shadow fading | | | | | | | | | | | | |
| | multipath fading | | | | | | | | | | | | |
| | interference | | | | | | | | | | | | |
| | jamming | | | | | | | | | | | | |

Legend

strong dependency

weak dependency

no dependency

2.3.2 Waveform Description and Mutual Impact on Channel Model

The digital waveform that gives a software defined radio the “soul” or its main functionality, is driven during development process by different dependencies (Figure 5).

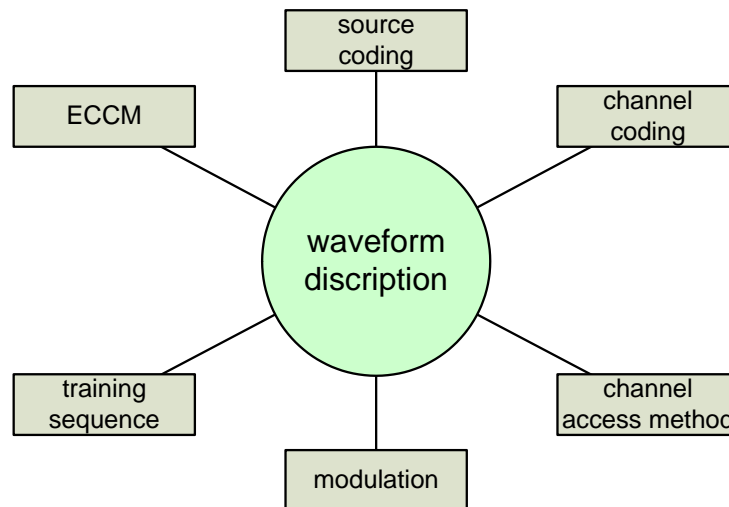


Figure 5: Waveform Description and Related Dependencies.

- *source coding:*

Dependent on the content of the transmission as stated in the operational scenario, source coding might be required. An example of this would be the coding of an audio input using CELP (Code-Excited Linear Prediction) in order to minimize the amount of data which has to be transmitted via the wireless link.

- *channel coding:*

In order to overcome the impairments to the signal introduced by the wireless channel error correction schemes like Automatic Repeat reQuest (ARQ) or Forward Error Correction (FEC). In the event of a detected error ARQ usually initiates a retransmission of the affected packet whereas FEC attempts to correct the error using previously inserted redundant information. The selection of a suitable channel coding scheme is highly dependent on the properties of the wireless channel simulated by the channel model.

- *channel access method:*

The channel access method defines the way in which different users access the wireless channel as a common resource. Various types of channel access like Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA) or Space Division Multiple Access (SDMA) are viable and should be chosen dependent on the characteristics of the channel and the restrictions given by the scenario.

- *modulation:*

The modulation scheme used by the waveform significantly influences the signal characteristics. When defining this essential waveform property it is important to incorporate not only the characteristics of the channel but also the restrictions given by the hardware.

- *training sequence:*

Dependent on the channel characteristics it might be necessary to insert an appropriate training sequence in the data stream. Doing this, the receiver is able to estimate the channel state information more accurate

and reliable as in case of using blind estimation. The estimated channel state information is necessary for the equalisation of the distorted signal in the receiver.

- *ECCM*:

When offensive Electronic Counter Measures (ECM) in the form of jamming through a hostile third party are expected, Electronic Counter Counter Measures (ECCM) like frequency hopping or Direct Sequence Spread Spectrum (DSSS) have to be implemented in the waveform.

Following on the next page the dependencies of waveform description and channel model influences in Table 3 are presented as a summary for this chapter again.

Table 3: Dependency of Waveform Description from Channel Model Influences.

| | | Channel model | | | | | |
|----------------------|-----------------------|--------------------|-----------|---------------|------------------|--------------|---------|
| | | modelling approach | path loss | shadow fading | multipath fading | interference | jamming |
| Waveform description | source coding | | | | | | |
| | channel coding | | | | | | |
| | channel access method | | | | | | |
| | modulation | | | | | | |
| | training sequence | | | | | | |
| | ECCM | | | | | | |

Legend

| | |
|--|-------------------|
| | strong dependency |
| | weak dependency |
| | no dependency |

The large number of ‘strong dependencies’ figure out, as already mentioned, the close intermeshing between waveform description and channel model.

3.0 CONCLUSION

A method based on ‘scenario based’ analysis was exemplarily presented in detail for the definition of the channel model and the waveform parameter for a wireless communication system for tactical software defined radios. The presented framework allows in general technical parameter setting tailored to operators needs while mutual dependencies of the parameter are considered. The decision process for the operator on the one hand and the given tailored specification for development engineer on the other hand could be optimized by the presented method and approach.

4.0 ACKNOWLEDGEMENT

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